

BACK TO THE DRAWING BOARD: ON STUDYING INTERACTION WITH MECHANICAL DESIGN

Leah F. Rosenbaum
University of California, Berkeley
leahr@berkeley.edu

Dor Abrahamson
University of California, Berkeley
dor@berkeley.edu

In a pilot study of an experimental calculus activity centered on the CalcMachine—a concrete manipulative—subjects visually “projected” the anticipated results of their actions before executing them. From these empirical findings, we tentatively argue for integrating two theoretical models: distributed cognition (Kirsh, 2009) and instrumental genesis (Vérillon & Rabardel, 1995). Emerging from a study in the concrete domain, this theoretical development may bear implications also for digital interactive educational technologies.

Keywords: Cognition, Design Experiments, Learning Theory, Technology

Education technology research in the 21st century increasingly focuses on electronic media (Hourcade, 2015), particularly in mathematics education (e.g., see Confrey et al., 2010). Yet this research draws on educational theory often based on interactions with now-antiquated media. We assert that new forms of interaction warrant re-conceptualization of learning, teaching, and educational design (Papert, 2004). In this paper, we take a step back in hopes of taking a few steps forward, turning our attention away from virtual manipulatives and toward concrete ones (Sarama & Clements, 2009). From studying how students learn to operate tangible devices within a concrete context, we hope to contribute to digital realms of interactive technology.

Reporting on a modest study from a design-based research practicum, we first explain the design problem that inspired this project. We then propose a theoretical contribution of the pilot study and introduce two case studies as applications. We end by reframing the study as a case of our larger argument for the value of dabbling in “low tech” to inform innovation in “high tech.”

A Pilot Study

The problematic role of calculus as an academic gatekeeper (Steen, 1988) motivated us to improve students’ first encounters with calculus. Inspired by arguments for the inherently embodied nature of mathematics (Nemirovsky, 2003), we created an embodied learning environment (Abrahamson, 2014) to motivate and steer students’ goal-oriented actions and descriptions thereof toward normative disciplinary practices (Abrahamson & Trninic, 2015).

Design

We designed, built, and pilot-tested the CalcMachine (see Figure 1a, next page), a 1-foot square frame containing: (I) a metal curve approximating a parabola; (II) a drawing bar; and (III) two magnetic points attaching the drawing bar to the curve. The points slide along a slit in the drawing bar, allowing it to be adjusted along the curve at various locations and angles. Users trace against the bar to draw secant and tangent lines to the curve.

Students’ activity with CalcMachine centers on a set of target images (see Figure 1b, next page). Students are asked to recreate these images with the device. For each image, they are to set the drawing bar at an appropriate location on the curve and then use a pencil so as to trace a line on a sheet of paper placed under the device. The images were designed to promote motor-action schemes presumed as relevant to reasoning about secants and tangents. The rationale was to orient subjects toward relationships between the curve, action schemes, and resulting shapes.

Methods

The subjects, one mid-20s male and one mid-60s female, do not reflect the ultimate target population but were auspicious for this paper, as they could articulately reflect on their work. Interviews began by introducing the CalcMachine, demonstrating how to draw, and then inviting the subject to explore. Once subjects drew comfortably, the target images (Figure 1b) were introduced. Subjects were asked to draw a target image of interest and explain his/her process.

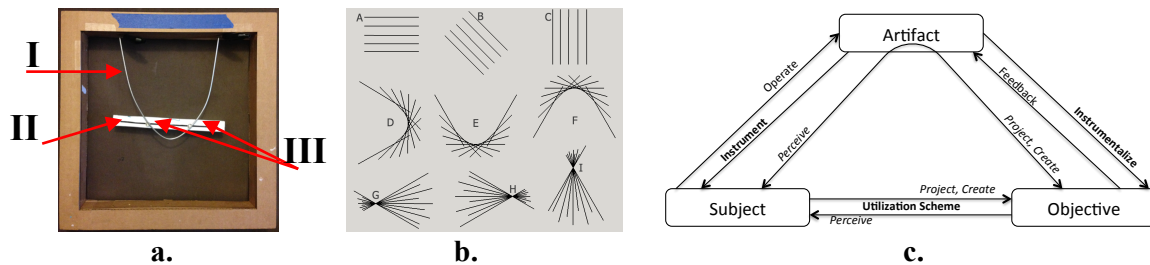


Figure 1. a. CalcMachine prototype. b. Target Images. c. Diagram for theoretical integration of IAS (bold font) & Distributed Cognition (italicized font).

Theory Interlude: Toward Integrating Seminal Frameworks

Subjects spent significant time orienting themselves toward operating the CalcMachine and applying it as a drawing tool. We believe this orienting work profoundly shaped their learning. Here we present two relevant theoretical frameworks as well as a proposed integration thereof.

Instrumental Genesis

Vérillon and Rabardel's (1995) *instrumented activity situations (IASs)* capture the multi-directional interactions among a Subject who learns to use an Artifact to facilitate an Objective (see Figure 1c, above). Examples for IASs include using an abacus to do sums or using written words to communicate. As the subject learns to operate the artifact, the artifact **instruments** the subject, limiting the subject's actions to those within the artifact's constraints. As the subject learns to use the artifact toward the objective, the artifact is **instrumentalized**, becoming a tool for the task. Feedback from the objective during instrumentalization surfaces new capabilities and constraints of the artifact, further instrumenting the subject. Through instrumented action and in keeping with cultural norms, subjects develop **utilization schemes (USs)** through which they interact with and imagine the objective. USs reflect instrumentation and instrumentalization, narrowing the subject's actions and perceptions to those afforded by the artifact. We use the IAS framework to analyze how subjects: (1) learn to operate the CalcMachine; (2) instrumentalize it to achieve the drawing objective; and (3) become instrumented as users of the CalcMachine.

Distributed Cognition

In addition to the system-level IAS framework, we also seek a perspective on moment-to-moment work. We observed nonstandard instrumentalizations of the CalcMachine that suggested the subjects' thinking to be distributed through the artifact onto the task environment. Kirsh's (2009) construct of 'projection' helps us clarify such subject–environment interactions.

Projection captures features of the environment that we visualize despite their not being physically present. For example, when solving a geometry problem, we might visualize a line bisecting an angle even though such a line is not yet physically in the environment. Projection is often paired with *creation*, either by gesturing or constructing something in the environment to materialize a projection. The former projection now perceptible, the freed cognitive resources can be put to other uses, allowing iterated projection perhaps by visualizing greater detail (as in the geometry problem). In social settings, creation may occur as much, or more, for an observer as for

the subject him/herself, transforming a private projection into a shared discursive element.

A Proposed Integration

We propose integrating project–create into the IAS triangle (see Figure 1c, previous page). We offer that ‘project’ and ‘create’ illuminate particular instances of sensorimotor feedback that shape broader instrumentation, instrumentalization, and utilization schemes. Thus subjects can project–create onto the Object, either via the Artifact, thus further instrumentalizing it, or directly onto the Object. In the latter case, implicit utilization schemes likely mediate the direct projection–creation. We find support for this theoretical integration in the task-based interviews.

Findings

In these excerpts project–create seems to co-occur with, and serve, novel instrumentalization. We also interpret moments of project–create as suggesting nascent utilization schemes.

Projected Parabolas

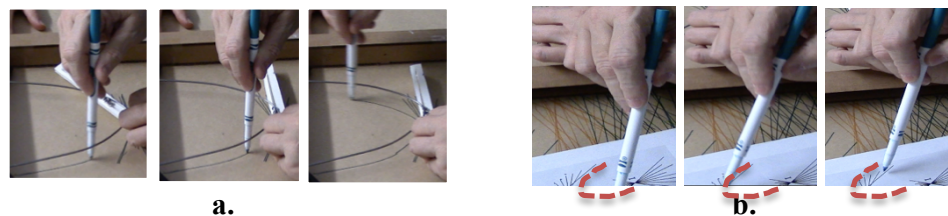


Figure 2. a. Traced parabola against the curve. b. Gestured parabola on Target Image F.

Working on Target Image F, Karen traced a parabola against the curve (Figure 2a) and then indicated an analogous parabola on Target Image F (Figure 2b), where drawing curves thus was a novel instrumentalization of the CalcMachine. Karen’s drawn and gestured creation of parabolas not present in the environment suggests she had projected them and also indicates a utilization scheme; Karen may view the target images as things in which to recognize parabolas.

Projected Tangents

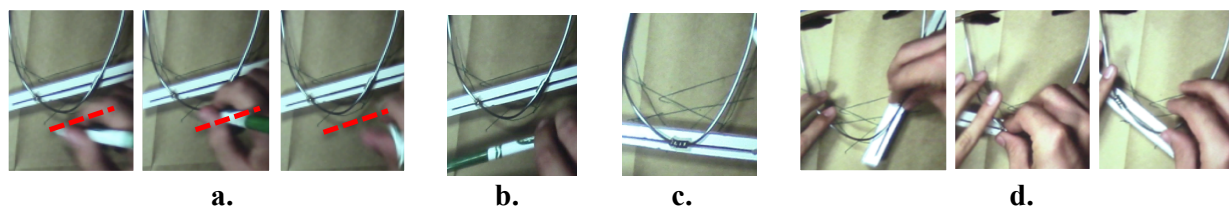


Figure 3. a. Gestured tangent. b. Marker as tangent. c. Drawing bar as tangent. d. Drawing bar itself utilized spontaneously as constituting a tangent line at various locations.

Drew considered moving the drawing bar with the points adjacent. He gestured a line roughly tangent to the curve (Figure 3a), indicating a line projected there, then materialized this projection with the marker (Figure 3b). This direct creation suggests a conception of the space as comprising such lines, a utilization scheme in step with Drew’s academic background in calculus. He also recreated his projection and achieved novel instrumentalization by placing the drawing bar along the formerly gestured path (Figure 3c) and other tangent locations (Figure 3d).

Summary

From these pilot cases, we tentatively advance two propositions integrating project–create into

IAs. First, project–create cycles may facilitate novel instrumentalization. The temporal link between actions/utterance indicating both project–create and novel instrumentalization suggests that such instrumentalization may be a specific case of project–create, where an intended action with the artifact (or an intended product of that action) is projected before it is materialized by using (elements of) the artifact. Second, direct projection–creation onto the environment carries subjects’ developing conceptions of legitimate Subject–Objective interactions in that space—a utilization scheme for both artifact and environment. These tentative conjectures require further evaluation, particularly in capturing novel instrumentalizations and nascent utilization schemes.

Based on these proposals, we submit that projection, from cognitive science, can contribute to education research, specifically to micro-analytic investigations of mathematics learning.

Conclusions

Calculus’s role as an academic gatekeeper (Steen, 1988) motivated us to undertake a design-based research study using embodied learning. We designed, built, and pilot-tested the CalcMachine, a dynamic tangible device for exploring derivatives. Pilot study observations prompted us to integrate theories of instrumental genesis (Vérillon & Rabardel, 1995) and distributed cognition (Kirsh, 2009) to better understand subjects’ work to operate a novel artifact.

We submit that our insights from this project emerged because we stepped back into the concrete. We likely would not have included in a virtual CalcMachine any function for tracing against the curve or using the marker as a line rather than a drawing tool, actions that—in the task context—represent failures. Yet these very failed attempts at normative operation rendered transparent the artifact’s embedded functionalities, in turn offering us glimpses into authentic and ultimately productive learning processes en route to normative actions. Even as we advance with the innovations of interaction technology, we also pause to consider interaction affordances of physical artifacts—exploration and transparency among them—that we risk leaving behind. These affordances, in turn, also enabled us to step back and integrate theoretical models.

References

- Abrahamson, D. (2014). Building educational activities for understanding: an elaboration on the embodied-design framework and its epistemic grounds. *International Journal of Child-Computer Interaction*, 2(1), 1-16.
- Abrahamson, D., & Trninic, D. (2015). Bringing forth mathematical concepts: Signifying sensorimotor enactment in fields of promoted action. *ZDM Mathematics Education*, 47(2), 295–306.
- Confrey, J., Hoyles, C., Jones, D., . . . Pratt, D. (2010). Designing software for mathematical engagement through modeling *Mathematics education and technology—Rethinking the terrain* (pp. 19-45). NYC: Springer.
- Hourcade, J. P. (2015). *Child-computer interaction*. <http://homepage.cs.uiowa.edu/~hourcade/book/index.php>
- Kirsh, D. (2009). Projection, problem space and anchors. In T. N. H. van Rijn, & L. Schomaker (Eds.), *Proceedings of the 31st conference of the Cognitive Science Society* (pp. 2310-2315). Mahwah, NJ: Lawrence Erlbaum.
- Nemirovsky, R. (2003). Three conjectures concerning the relationship between body activity and understanding mathematics. In N. A. Pateman, B. J. Dougherty, & J. T. Zilliox (Eds.), *Proc. of the 27th annual meeting of PME* (Vol. 1, pp. 105-109). Columbus, OH: Eric Clearing House.
- Papert, S. (2004). Keynote Speech. In E. McKay (Ed.), *Proceedings of the International Conference on Computers in Education (ICCE)*. Sydney: University of Sydney. <http://vimeo.com/9092144>
- Sarama, J., & Clements, D. H. (2009). “Concrete” computer manipulatives in mathematics education. *Child Development Perspectives*, 3(3), 145-150.
- Steen, L. A., National Research Council (U.S.), National Research Council (U.S.), Mathematical Association of America, National Academy of Sciences (U.S.), & National Academy of Engineering (1988). *Calculus for a new century: A pump, not a filter—A national Colloquium, Oct. 28-29, 1987*. Washington, D.C.: MAA.
- Vérillon, P., & Rabardel, P. (1995). Cognition and artifacts: A contribution to the study of thought in relation to instrumented activity. *European Journal of Psychology of Education*, 10(1), 77-101.